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Published in:
Current Science

Publication date:
2009

Citation for published version (APA):
Grande, M., Maddison, B. J., Sreekumar, P., Huovelin, J., Kellett, B. J., Howe, C. J., Crawford, I. A., Smith, D. R., & Team, T. C. X. S. (2009). The Chandrayaan-1 X-ray spectrometer. *Current Science*, *96*(4), 517-519. http://www.currentscience.ac.in/Downloads/article_id_096_04_0517_0519_0.pdf

The Chandrayaan-1 X-ray Spectrometer

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The Chandrayaan-1 X-ray Spectrometer (C1XS) is a compact X-ray spectrometer for the Chandrayaan-1 lunar mission. It exploits heritage from the D-C1XS instrument on ESA's SMART-1 mission. C1XS is designed to measure absolute and relative abundances of major rock-forming elements (principally Mg, Al, Si, Ti, Ca and Fe) over the lunar surface. The baseline design consists of 24 nadir pointing Swept Charge Device detectors, which provide high detection efficiency in the 1–7 keV range, which contains the X-ray fluorescence lines of the above elements of interest. Micromachined collimators provide a 14 degree FWHM FOV, equivalent to 25 km from 100 km altitude. A deployable door protects the instrument during launch and cruise, and also provides a ^{55}Fe calibration X-ray source for detector calibration. Additional refinements compared to D-C1XS will result in a significantly improved energy resolution. To record the incident solar X-ray flux at the Moon, C1XS carries an X-ray Solar Monitor (XSM). C1XS will arrive at the Moon in the run up to the maximum of the solar cycle 24, and the expected high incident X-ray flux coupled to a 100 km circular polar orbit, will provide composition data accurate to better than 10% of major elemental abundances over the lunar surface.

Keywords: Chandrayaan-1, elemental abundances, Moon, X-ray spectrometer.

Introduction

BASED on the heritage of the D-C1XS instrument[1,2] on ESA's SMART-1 mission, the Chandrayaan-1 X-ray Spectrometer (C1XS) is a compact X-ray spectrometer for the Indian Space Research Organisation (ISRO) Chandrayaan-1 remote sensing mission to the Moon. C1XS is designed to measure absolute and relative abundances of major rock-forming elements (principally Mg, Al, Si, Ti, Ca and Fe) in the lunar crust with spatial resolution ~25 km.

C1XS is built and operated by an international team led from the Rutherford Appleton Laboratory, UK, with major science and design contribution from ISRO Satellite Centre, Bangalore, India. CESR, Toulouse, France provides amplifier assemblies, and there is an important contribution to the detector development from Brunel University, UK. In order to record the incident solar X-ray flux at the Moon, C1XS carries an X-ray Solar Monitor (XSM) provided by the University of Helsinki, Finland.

Instrument

Figure 1 shows the baseline design, which consists of 24 nadir pointing Swept Charge Device (SCD) detectors. Each detector is filtered with 400 nm of Al on 400 nm of polymer substrate, which provide high detection efficiency in the 1–7 keV range that covers the X-ray fluorescence lines of interest. The SCD is a CCD-like device which achieves near Fano-limited spectroscopy below –10°C. It is read out is similar to a conventional CCD, requiring 575 clock triplets to read out the 1.1 cm^2 detector

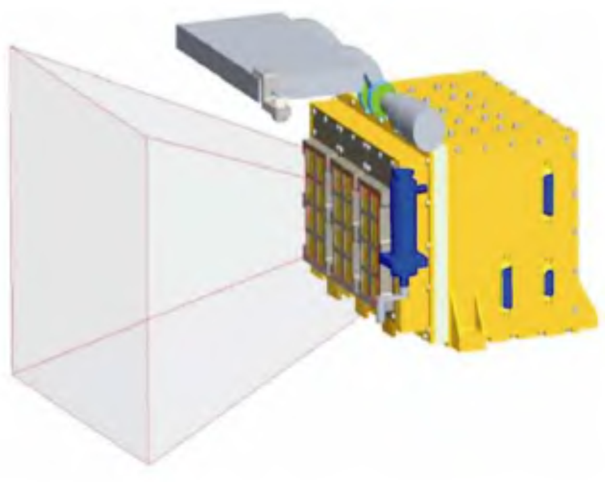

Figure 1. Design image of the C1XS instrument showing coalligned front detectors, deployable radiation shield and 14° field of view. Note white thermal gasket separating cool detector enclosure from electronics.

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area. Micro-machined collimators provide a 14 degree FWHM FOV, equivalent to 25 km from 100 km altitude. A deployable door protects the instrument during launch and cruise, and also provides a ^{55}Fe calibration X-ray source for onboard detector calibration.

Appropriate care has been taken to ensure adequate radiation shielding, in what is already a comparatively low radiation environment orbit. It consists of a 4 mm thick aluminum electronics box with 3 mm of copper and 6 mm of tantalum behind the SCD modules. Due to the low altitude, the spacecraft is well shielded from the front by the Moon itself.

Additional refinements to the electronics, onboard software and thermal design will also greatly increase detector stability and signal to noise ratio over what was achieved on D-C1XS[1]. This will result in a significantly improved energy resolution that is expected to be better than 250 eV throughout the lifetime of the mission[3,4]. The flight model of C1XS baring the collimator and the deployable door is shown in Figure 2.

X-ray solar monitor

The X-ray solar monitor (XSM) consists of a separate silicon detector unit on the spacecraft. The non-imaging HPSi PIN sensor has a wide field-of-view (FOV) to enable sun visibility during a significant fraction of the mission lifetime, which is essential for obtaining calibration spectra for the X-ray fluorescence measurements by the imaging C1XS spectrometer. The energy range (1–20 keV), spectral resolution (about 250 eV at 6 keV), and sensitivity (about 7000 cps at flux level of 10^{-4} W m^{-2} in the range 1–8 Å) are tuned to provide optimal knowledge about the solar X-ray flux on the lunar surface, matching well with the activating energy range for the fluorescence lines measured by C1XS.

Science goals

To a large extent the scientific objectives of C1XS mirror those identified for D-C1XS[5], but the greater spatial and spectral resolutions anticipated for C1XS mean that it will be possible to address rather more specific science goals than were identified for the former instrument. The science objectives bear on important questions of lunar crustal and mantle evolution, and will provide further insights into our understanding of the origin of the Moon.

C1XS will arrive at the Moon in the run up to the maximum of the solar cycle 24, and the high incident X-ray flux observed from an 100 km circular polar orbit optimized for science, and coupled with the good instrumental energy resolution demonstrated in the laboratory[3,4] (see Figure 3), means that we will obtain composition data accurate to better than 10% of major elemental (Mg, Al, Si) abundances over the lunar surface and also of heavier elements (Ca, Ti, Fe) over specific areas covered during major solar flares. Elemental abundances inferred for Apollo and Luna sampling sites will provide calibration data for validating C1XS data processing and analyses algorithms.

C1XS will provide data on major element geochemistry (and especially Mg/Si and/or Mg/Fe) in the main lunar terrain types (i.e. Procellarum KREEP Terrain, South Pole-Aitken Basin, and the Farside Highlands) and establish the geographical distribution of magnesian suite rocks. One of the important scientific objectives is to determine the large-scale stratigraphy of lower crust (and

Figure 2. View of the C1XS flight instrument during integration. The collimator assembly and doors have not yet been added, so that the 24 swept-charge detectors, arranged in ladders of four, are clearly seen.

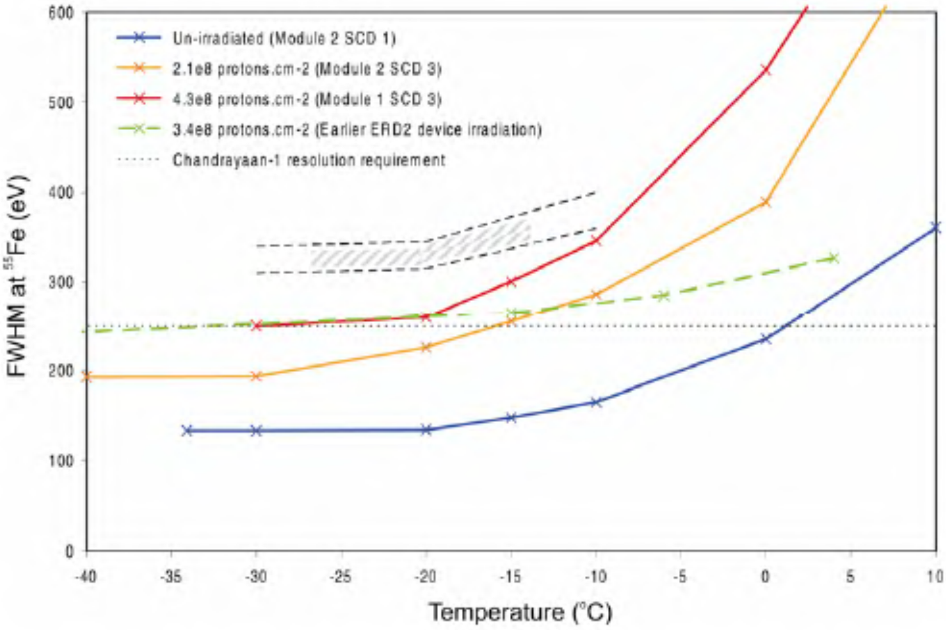

Figure 3. Swept charge device FWHM at Mn–Kα (5.9 keV) vs temperature, before and after radiation testing. The specified maximum operating temperature is –17.5°. Note the favourable comparison with D-C1XS performance shown in between the dashed lines.

possibly crust/mantle boundary region) by measuring the elemental abundances of the floor material of large basins not obscured by mare basalts (e.g. SPA and other farside basins), and the central rings and ejecta of large basins (whether flooded or not) which expose material derived from depths of many tens of km. Aluminium abundance maps will constrain models of the global melting event that produced the Al-rich crust. Aluminium abundance and distribution are also essential for an assessment of lunar refractory element enrichment. Additionally, the ~25 km spatial resolution enables C1XS to address a number of smaller-scale geological issues which also refine our understanding of lunar geological evolution.

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ACKNOWLEDGEMENT. C1XS is primarily supported by ESA with partial support to RAL from ISRO.

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